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Blood Lead Levels in U.S. Children Ages 1–11 Years, 1976–2016

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Background: Lead can adversely affect child health across a wide range of exposure levels. We describe the distribution of blood lead levels (BLLs) in U.S. children ages 1–11 y by selected sociodemographic and housing characteristics over a 40-y period.

Methods: Data from the National Health and Nutrition Examination Survey (NHANES) II (1976–1980), NHANES III (Phase 1: 1988–1991 and Phase II: 1991–1994), and Continuous NHANES (1999–2016) were used to describe the distribution of BLLs (in micrograms per deciliter; 1 μg/dL = 0.0483 μmol/L) in U.S. children ages 1–11 y from 1976 to 2016. For all children with valid BLLs ($n = 27{,}122$), geometric mean (GM) BLLs [95% confidence intervals (CI)] and estimated prevalence ≥5 μg/dL (95% CI) were calculated overall and by selected characteristics, stratified by age group (1–5 y and 6–11 y).

Results: The GM BLL in U.S. children ages 1–5 y declined from 15.2 μg/dL (95% CI: 14.3, 16.1) in 1976–1980 to 0.83 μg/dL (95% CI: 0.78, 0.88) in 2011–2016, representing a 94.5% decrease over time. For children ages 6–11 y, GM BLL declined from 12.7 μg/dL (95% CI: 11.9, 13.4) in 1976–1980 to 0.60 μg/dL (95% CI: 0.58, 0.63) in 2011–2016, representing a 95.3% decrease over time. Even so, for the most recent period (2011–2016), estimates indicate that approximately 385,775 children ages 1–11 y had BLLs greater than or equal to the CDC blood lead reference value of 5 μg/dL. Higher GM BLLs were associated with non-Hispanic Black race/ethnicity, lower family income-to-poverty-ratio, and older housing age.

Discussion: Overall, BLLs in U.S. children ages 1–11 y have decreased substantially over the past 40 y. Despite these notable declines in population exposures to lead over time, higher GM BLLs are consistently associated with risk factors such as race/ethnicity, poverty, and housing age that can be used to target blood lead screening efforts. https://doi.org/10.1289/EHP7932

Introduction

Lead can adversely affect child health across a wide range of biological markers of exposure and no safe level of lead in children has been identified (ACCLPP 2012). Adverse neurobehavioral effects of lead exposure in young children, as measured by blood lead levels (BLLs), are well-known (ACCLPP 2012; Bellinger and Needleman 2003; Lanphear et al. 2005). Studies have consistently documented negative effects of lead on cognitive function and attention-related and behavioral problems (NTP 2012). Low-level exposure, including BLLs of <5 and <10 μg/dL, have been associated with decreases in academic performance in school-age children (McLaine et al. 2013; Min et al. 2009; Miranda et al. 2009). Recent studies suggest that effects of childhood lead exposure on cognitive function and socioeconomic status (SES) may persist into adulthood (Reuben et al. 2017).

Since 1976, the National Health and Nutrition Examination Survey (NHANES) has estimated lead exposure for the U.S. population through BLLs measured in adults and children. Previous analyses of NHANES data indicate that BLLs in U.S. children have generally declined over time (Caldwell et al. 2017; Jones et al. 2009; Pirkle et al. 1994; Raymond et al. 2014). These declines have largely been achieved through federal regulations, including the removal of lead in gasoline and the banning of both lead-based paint and lead plumbing solder for residential uses, as well as applied public health efforts (Dignam et al. 2019). Despite these overall population declines in exposure to lead, recent high-profile events, such as the Flint Water Crisis, have highlighted ongoing sources of lead exposure in children (Hanna-Attisha et al. 2016; Ruckart et al. 2019). Persistent lead hazards in the environment include deteriorating lead-based paint and dust in housing built before 1978; lead-contaminated soil from paint and petroleum products; lead pipes, fixtures, and solder in household plumbing; aviation fuel; and existing hazardous waste sites (President's Task Force on Environmental Health Risks and Safety Risks to Children 2018). Additionally, children may come into contact with other preventable sources of lead exposure through family members by occupational take-home lead, use of traditional or folk medicines, and hobbies such as making fishing sinkers, bullets, stained glass, and ceramic glazes (Alarcon 2016). Lead has also been found in consumer products such as vitamins, cosmetics, spices, and certain foods (Pfadenhauer et al. 2016).

Previous NHANES analyses of BLL data have compared trends in children over select time periods, age groups, and sociodemographic characteristics (Jones et al. 2009; Pirkle et al. 1994, 1998; Tsoi et al. 2016). For example, in the 2007–2010 NHANES survey cycles, at least half a million children ages 1–5 y were estimated to have BLLs above the Centers for Disease Control and Prevention (CDC) blood lead reference value of 5 μg/dL, with higher prevalence among non-Hispanic Black or poor children (Wheeler and Brown 2013). However, these estimates did not include older children (i.e., ages 6–11 y or older). In addition, lead in drinking water is a potential source of elevated BLLs in school-age children; recent studies have documented lead in drinking water in public water systems, including in some U.S. school districts (Renner 2009; Triantafyllidou et al. 2014). Additionally, there are at least 500,000 U.S. women of childbearing age exposed to lead at levels that may pass to developing fetuses and breastfeeding infants (Ettinger et al. 2020).

To date, there has been no comparable analyses of BLLs in children over the entire 40-y period. We used NHANES data to describe the distribution of BLLs in U.S. children ages 1–5 and 6–11 y from 1976 to 2016 by selected sociodemographic and housing characteristics.

Methods

NHANES Sample Design

NHANES is a nationally representative, cross-sectional survey of the resident civilian noninstitutionalized U.S. population designed

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to monitor the nation's health and nutritional status. Prior to 1999, NHANES was conducted on a periodic basis. The NHANES II (1976–1980) and NHANES III (Phase I: 1998–1991 and Phase II: 1991–1994) survey designs and blood lead measurements have been described previously (Brody et al. 1994; CDC 1985; Pirkle et al. 1994, 1998). Since 1999, NHANES has been a continuous survey conducted on an ongoing basis among a representative sample of all ages, as previously described (CDC 2019). Approximately 5,000 NHANES participants per year are selected through a complex, stratified, multistage probability sampling design for a personal interview and a standardized physical examination. The survey collects information on chronic disease prevalence and risk factors, diet and nutritional status, immunization status, infectious disease prevalence, health insurance, and measures of environmental exposures. The household interview includes questions about sociodemographic characteristics, health history, health-related behaviors, and access to health care.

The NHANES protocol was developed and reviewed to be in compliance with the HHS Policy for Protection of Human Research Subjects (45 CFR part 46, available from http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.html). In accordance with federal regulations (45 CFR 46.111), the NCHS Research Ethics Review Board reviewed and approved NHANES protocols, including ongoing changes to the protocol through the amendment process. Informed consent was obtained from sample persons who had reached the age of maturity in their state (usually age 18 y and over); a parent or guardian gave permission for minors to participate, and an adult proxy provided household survey data on behalf of children ages 1–15 y. In addition, children ages 7–17 y provided documented assent prior to participating. An emancipated minor did not need parental permission. Detailed information about NHANES is available at https://www.cdc.gov/nchs/nhanes/index.htm.

We accessed NHANES data following submission of an approved research protocol through the National Center for Health Statistics (NCHS) Research Data Center (RDC) in Atlanta, Georgia, because our analyses involved restricted-use data (geographic variables). Restricted data includes information that could compromise the confidentiality of survey respondents, study subjects, or institutions, or information that is sensitive in nature. Our study involved secondary data analysis that did not constitute "human subjects research" and was thus exempt from additional CDC Institutional Review Board approval.

Blood Lead Measurements

Whole blood specimens were collected by venipuncture from eligible participants ages 1 y and older during the physical examination (Paschal et al. 1995). For NHANES II only, half of all children ages 7 y and older were selected for a blood lead measurement, whereas all children ages 1–6 y were eligible. Blood specimens are analyzed for lead concentration by the Division of Laboratory Sciences at the National Center for Environmental Health of the Centers for Disease Control and Prevention (CDC). Laboratory methods for NHANES II (CDC 1985), NHANES III (Gunter et al. 1996), and NHANES 1999–2016 (Jones et al. 2009) have been described previously. The limit of detection (LOD) for blood lead decreased from $2.0\ \mu g/dL$ in NHANES II (1976–1980) to $0.07\ \mu g/dL$ in NHANES 2013–2014 (current LOD) as technology improved (Caldwell et al. 2017). NHANES imputes results below the lower detection limit and replaces them with a value equal to the detection limit divided by the square root of 2 (CDC 2009).

Sociodemographic Characteristics

All analyses were stratified by age group: 1–5 and 6–11 y. Additionally, age was categorized as: 1–2, 3–5, 6–8, and 9–11 y for subgroup analyses due to differences in lead exposure risk behaviors by age. Race/ethnicity was self-identified and self-reported according to mutually exclusive categories based on relevant U.S. Census race/ethnicity questions at the time of survey. Racial and ethnic groups were characterized based on responses to questions about race and Hispanic origin. Race/ethnicity was categorized as non-Hispanic White, non-Hispanic Black, Mexican American, other Hispanic, and "other race" (which includes individuals reporting more than one race). The category "other Hispanic" was not available as a survey response for NHANES II and III, and "other race" was not available as a survey response in NHANES II. Birthplace was categorized as United States, Mexico, or other for all survey cycles.

SES was categorized using the family income-to-poverty ratio (FIPR) (equal to the ratio of total family income to the federal poverty threshold for the year of the interview) stratified as <1.3 and ≥ 1.3 (corresponding to income eligibility guidelines of 130% poverty level for supplemental nutrition programs) (CBPP 2019; Pirkle et al. 1998). We included health insurance coverage, Medicaid status, and participation in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), as available. These variables were not available for NHANES II. For NHANES III, health insurance coverage, Medicaid status, and participation in WIC were defined as being covered or receiving benefits in the past month, whereas for NHANES 1999–2016 coverage/participation was defined as coverage during the past 12 months. Health insurance coverage was queried as "Are you covered by health insurance or some other kind of health care plan? This includes private health insurance obtained through employment or purchased directly, as well as government programs, such as Medicare, Medicaid, SCHIP, military health care, Indian Health Service, State health plan, etc. that provide medical care or help pay medical bills." Participation in WIC (children ages 1–5 y) was only available in NHANES between 1999 and 2016.

Housing Age

"Year housing was built" used different categories for NHANES III and NHANES 1999–2010. Housing age was categorized in NHANES III as pre-1946, 1946–1972, 1973 to present, and unknown. From 1999 to 2010, NHANES categorized housing age as pre-1950, 1950–1977, 1978 to present, and unknown. Observations for which housing age was unavailable were recorded as unknown. Housing age was not collected in NHANES II or in the 2011–2016 surveys.

Geographic Variables

All geography below the national level is restricted for continuous NHANES due to disclosure risk; prior to 1999 all geography below the regional level is restricted; thus this information was accessed at the RDC.

Urbanization was defined based on county of residence using the NCHS six-level urban-rural classification scheme for U.S. counties and county-equivalent entities (https://www.cdc.gov/nchs/data_access/urban_rural.htm). In NHANES II, urbanization was classified as urbanized area ≥ 1 million, urbanized area <1 million, urban place outside of urbanized area, rural areas, central cities, and noncentral cities; we collapsed this variable to categories similar to NHANES III in which urbanization was dichotomized as counties of metropolitan areas ≥ 1 million or all other areas (<1 million). In NHANES 1999–2016, urbanization was defined as large metropolitan (population ≥ 1 million), medium and small metropolitan (population <1 million), or nonmetropolitan. Urbanization classification for years 1999–2016 was based on the NCHS urban, rural classification schemes

(1990 classification scheme for years 1999–2002, 2006 classification scheme for years 2003–2010, and 2013 classification scheme for 2011–2016) as assigned by the RDC (NCHS 2017). The NCHS metropolitan categories were collapsed for this analysis to increase sample size for subgroups and produce stable estimates based on the NCHS data presentation standards for proportions: metropolitan statistical areas (MSAs) with a population of 1 million or more; MSAs with a population of less than 1 million; and, for more recent survey cycles, areas outside of MSAs.

Geographic region was classified as Northeast, Midwest, South and West for all years. For NHANES 1999–2016, geographic region was categorized based on the 2010 Census Bureau's regions and is restricted data. Geographic region in NHANES II and III differs from the 2010 Census Bureau definition. Therefore, regional estimates cannot be directly compared across NHANES II, NHANES III, and NHANES 1999–2016.

Statistical Analyses

All statistical analyses were completed using SAS (version 9.3; SAS Institute, Inc.) and SAS-callable SUDAAN (version 11.0.1; RTI International) software packages. Weighted estimates were produced using the examination sampling weight to account for unequal probabilities of selection, oversampling, and survey nonresponse as recommended by NHANES analytic guidelines (Johnson et al. 2013; McDowell et al. 1981; NCHS 1996). The cluster design was accounted for in estimating variances.

We used data on NHANES participants ages 1–11 y with valid blood lead measurements and grouped them according to age (1–5 y and 6–11 y) and survey period: NHANES II (1976–1980), NHANES III Phase 1 (1988–1991), NHANES III Phase 2 (1991–1994), and continuous NHANES 1999–2002, 2003–2006, 2007–2010, and 2011–2016. We grouped continuous NHANES data into 4-y and 6-y periods for analysis to increase the number of children in each group to yield more stable estimates. Table 1 shows the number and proportion of children with valid blood lead measurements available from among the total number of participants by age group and study cycle.

All analyses were stratified by age group: 1–5 and 6–11 y. Weighted estimates derived from the observed data for the study population using NHANES-specified sampling weights for the various survey cycles were used to estimate the number of children with BLLs greater than or equal to the CDC blood lead reference value (5 μg/dL) based on the U.S. population of children 1–11 y (NCHS: Response Rates and Population Totals, available at https://wwwn.cdc.gov/nchs/nhanes/ResponseRates.aspx). Geometric means (GM) and 95% confidence interval (CI) for BLLs and the estimated prevalence (%) of BLLs $\geq$5 μg/dL and 95% CI were calculated by age group (1–5 y and 6–11 y) overall and by selected characteristics. Formal statistical testing for differences in BLLs for each variable of interest was not completed. We also calculated the overall estimated prevalence (%) of BLLs $\geq$10 μg/dL and 95% CI for children ages 1–11 y in aggregate (shown in Figure 1) by survey cycle (years) due to the small cell sizes at higher BLLs, particularly in the later years. Although no safe BLL in children has been identified, the use of a dichotomous threshold for BLLs is advantageous because it is used for case surveillance and case management definitions and, as such, is more easily interpretable than statistically derived cut points. Prevalence estimates that had a relative standard error (RSE) of the estimate $\geq$30% were regarded as statistically unreliable (CDC 2018). All results of cell count sample sizes <5 or percentages calculated from numerators <5 are suppressed by the RDC due to disclosure concerns per the NCHS policy.

Table 1. Population estimate (*N*), total participants (*n*), and participants [*n* (%)] with valid BLL from among U.S. children (*n*) ages 1–11 y, and weighted estimates for prevalence (%) and 95% CI of BLL $\geq$5 μg/dL and number of children with BLL $\geq$5 μg/dL, by survey cycle (years) and age group (1–5 y and 6–11 y) in the NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY (NHANES), 1976–2016.

	Ages 1–5 y					Ages 6–11 y				
Survey cycle	Population estimate	Total participants	Participants with valid BLL	BLL $\geq$5 μg/dL	BLL $\geq$5 μg/dL	Population estimate	Total participants	Participants with valid BLL	BLL $\geq$5 μg/dL	BLL $\geq$5 μg/dL
Years	*N*	*n*	*n* (%)	% (95% CI)[a]	*n*	*N*	*N*	*n* (%)	% (95% CI)[a]	*n*
1976–1980	15,263,000[b]	3,762	2,360 (62.7)	99.8 (99.4, 99.9)	15,232,474	20,880,000[b]	1,725	830 (48.1)	99.7 (98.6, 99.9)	20,817,360
1988–1991	19,657,453[c]	3,278	2,232 (68.1)	31.4 (26.0, 37.3)	6,172,440	22,527,176[c]	1,943	1,584 (81.5)	15.0 (11.3, 19.7)	3,379,076
1991–1994	19,657,453[c]	2,876	2,392 (83.2)	21.0 (16.0, 27.0)	4,128,065	22,527,176[c]	1,524	1,345 (88.3)	9.5 (7.3, 12.2)	2,140,082
1999–2002	19,323,164[d]	2,415	1,621 (67.1)	8.7 (6.5, 11.5)	1,681,115	24,889,987[d]	2,355	1,949 (82.8)	3.0 (1.9, 4.6)	746,700
2003–2006	20,257,887[e]	2,677	1,879 (70.2)	4.1 (2.9, 5.8)	830,573	23,921,965[e]	2,179	1,790 (82.1)	1.3 (0.7, 2.6)[h]	310,986
2007–2010	20,870,073[f]	2,526	1,653 (65.4)	2.6 (1.7, 4.2)	542,622	24,055,655[f]	2,519	2,020 (80.2)	0.4 (0.2, 0.8)	96,223
2011–2016	20,171,918[g]	3,609	2,321 (64.3)	1.3 (0.7, 2.4)[h]	262,235	24,707,984[g]	4,031	3,146 (78.0)	0.5 (0.1, 0.5)[h]	123,540

Note: BLL, blood lead levels; CI, confidence interval.
[a]Weighted estimates derived from the observed data for the study population using NHANES-specified sampling weights.
[b]NHANES II: U.S. Noninstitutionalized population as of 1 March 1978 (approximate midpoint of the survey) from the U.S. Census Current Population Survey.
[c]NHANES III: U.S. population from combined 6-y sample, NHANES III data file, 1988–1994, from the U.S. Census Bureau Current Population Survey.
[d]Continuous NHANES 1999–2002: distribution of the civilian noninstitutionalized U.S. population for the midpoint of 1999–2002, from the U.S. Census Bureau Current Population Survey.
[e]Continuous NHANES 2003–2006: distribution of the civilian noninstitutionalized U.S. population for the average of 2003–2004 and 2005–2006 cycles, from the U.S. Census Bureau American Community Survey.
[f]Continuous NHANES 2007–2010: Distribution of the civilian noninstitutionalized U.S. population for the average of 2007–08 and 2009–10 cycles, from the U.S. Census Bureau American Community Survey.
[g]Continuous NHANES 2011–2016: distribution of the civilian noninstitutionalized U.S. population for the average of 2011–2012, 2013–2014, and 2015–2016 cycles, from the U.S. Census Bureau American Community Survey.
[h]Relative Standard Error (RSE) greater than or equal to 30% indicates estimate is statistically unreliable.

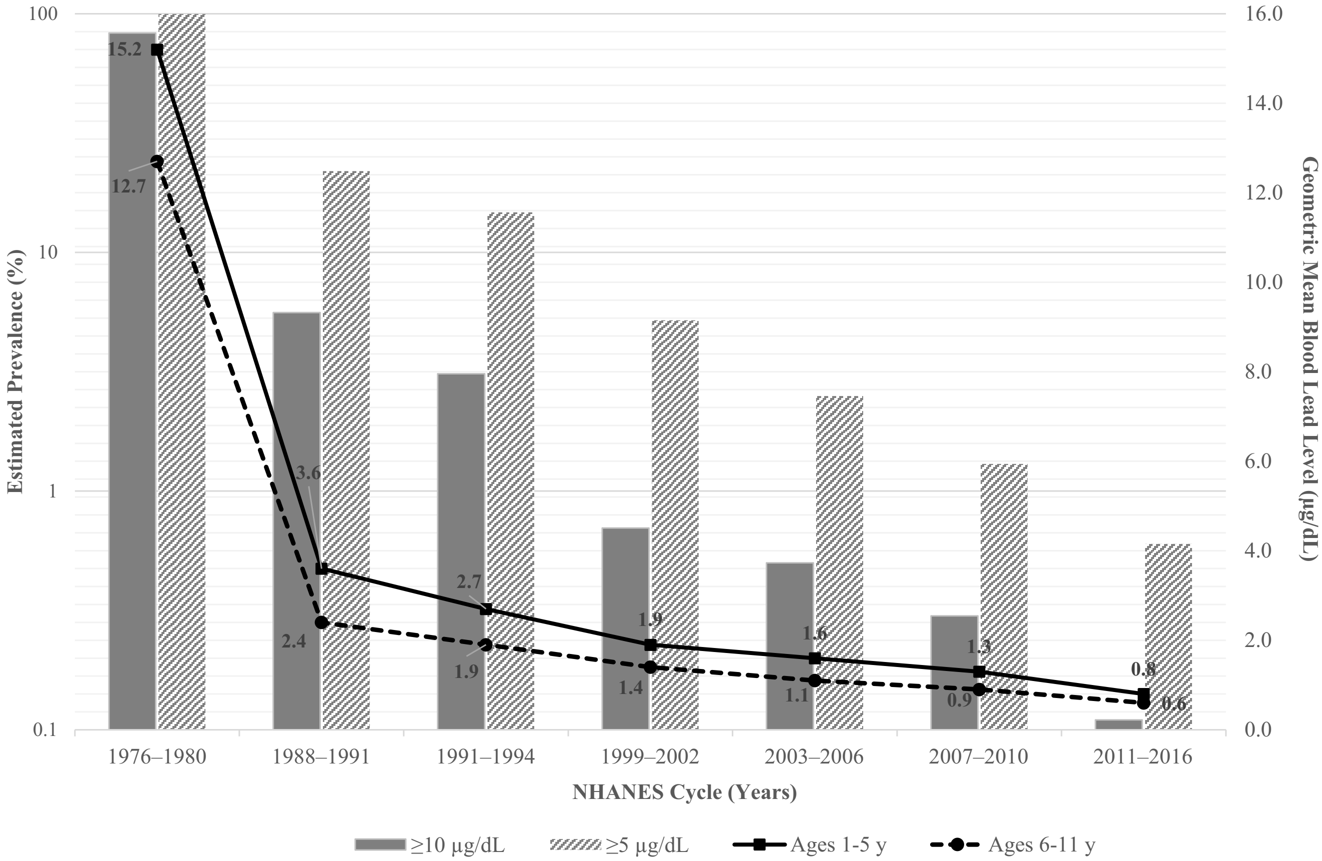

Figure 1. Estimated prevalence (%) of blood lead levels ≥10 µg/dL (gray bars) ≥5 µg/dL (hatched bars) among U.S. children ages 1–11 y plotted on the log-10 scale; geometric mean blood lead levels (µg/dL) for children ages 1–5 y (squares, solid line) and ages 6–11 y (circles, dashed line) in the National Health and Nutrition Examination Survey (NHANES), 1976–2016, by survey cycle (years); data shown in Table S1.

Results

The percentage of NHANES participants ages 1–5 and 6–11 y with valid blood lead measurements varied over time and ranged from 62.7 to 83.2% and 48.1 to 88.3%, respectively, over the 40-y period (Table 1). The estimated prevalence of children ages 1–5 y with a BLL ≥5 µg/dL sharply decreased from 99.8% in NHANES II (1976–1980) to 1.3% during 2011–2016. Similarly, for children ages 6–11 years, the estimated prevalence of BLL ≥5 µg/dL declined from 99.7% in NHANES II to 0.5% in 2011–2016. Figure 1 illustrates the downward trends in the estimated percentage of U.S. children ages 1–11 y with BLLs ≥5 and ≥10 µg/dL over time (Table S1). Nonetheless, in 2011–2016, an estimated 262,235 and 123,540 children ages 1–5 and 6–11 y, respectively, or 385,775 in total, had BLLs greater than or equal to the CDC blood lead reference value of 5 µg/dL (Table 1).

The GM BLL in U.S. children aged 1–5 y declined from 15.2 µg/dL (95% CI: 14.3, 16.1) in 1976–1980 to 0.8 µg/dL (95% CI: 0.8, 0.9) in 2011–2016 representing a 94.5% decrease over time (Table 2). For children ages 6–11 y, the GM BLL declined from 12.7 µg/dL (95% CI: 11.9, 13.4) in 1976–1980 to 0.6 µg/dL (95% CI: 0.6, 0.6) in 2011–2016, representing a 95.3% decrease over time (Table 3). A large proportion of these declines occurred before 1992, as the GM BLLs for ages 1–5 and 6–11 y, respectively, had decreased to 3.6 µg/dL (95% CI: 3.2, 4.0) and 2.4 µg/dL (95% CI: 2.1, 2.7) by 1988–1991 (Tables 2 and 3).

Throughout the survey periods, younger children had higher GM BLL than older children (Tables 2 and 3). In 1976–1980, the GM BLL for children ages 1–2 y was 15.7 µg/dL (95% CI: 14.5, 16.9) (Table 2). whereas the GM BLL for children ages 9–11 y was 12.3 µg/dL (95% CI: 11.5, 13.0) (Table 3). By 2011–2016, the GM BLL for children ages 1–2 y was 0.9 µg/dL (95% CI: 0.9, 1.0) (Table 2), whereas the GM BLL for children ages 9–11 years was 0.6 µg/dL (95% CI: 0.5, 0.6) (Table 3). Figure 2 shows selected percentiles of blood lead concentrations by age group for the continuous NHANES survey cycles (1999–2016) (Table S2).

Racial/ethnic disparities in GM also persisted, even in recent NHANES survey cycles. Higher GM BLLs were consistently observed in children of non-Hispanic Black race/ethnicity (in comparison with non-Hispanic White) across the two age groups and over time (Tables 2 and 3). Additionally, children born in Mexico consistently had higher GM BLLs (in comparison with those born in the United States). Children with family indicators of lower SES, such as FIPR below poverty, no health insurance, receiving Medicaid, and receiving WIC assistance, were also observed to have higher GM BLLs across the survey cycles in both age groups.

Due to the almost universal estimated prevalence of BLL ≥5 µg/dL in NHANES II, there were only slight observable differences in prevalence by the selected sociodemographic characteristics. However, in later survey cycles, overall estimated prevalence of BLL ≥5 µg/dL among children ages 1–5 y dropped from 31.4% (95% CI: 26.0, 37.3) in 1988–1991 to 21.0% (95% CI: 16.0, 27.0) in 1991–1994 (Table 4), and differences in prevalence of BLL ≥5 µg/dL by selected characteristics became more apparent at this lower threshold. Among children ages 6–11 y, estimated prevalence dropped from 15.0% (95% CI: 11.3, 19.7) to 9.5% (95% CI: 7.3, 12.2) over the same period (Table 5). Non-Hispanic Black race/ethnicity (in comparison with non-Hispanic White), being born in Mexico (in comparison with

Table 2. Weighted geometric mean and 95% CI for BLLs in μg/dL among U.S. children ages 1–5 y,[a] overall and by selected characteristics in the NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY (NHANES), 1976–2016.

	Geometric mean (95% CI) BLLs in μg/dL[a]													
Ages 1–5 y	*n*	1976–1980	*n*	1988–1991	*n*	1991–1994	*n*	1999–2002	*n*	2003–2006	*n*	2007–2010	*n*	2011–2016
Overall	2,360	15.2 (14.3, 16.1)	2,232	3.6 (3.2, 4.0)	2,392	2.7 (2.5, 3.0)	1,621	1.9 (1.8, 2.1)	1,879	1.6 (1.5, 1.7)	1,653	1.3 (1.3, 1.4)	2,321	0.8 (0.8, 0.9)
Age group														
1–2 y	721	15.7 (14.5, 16.9)	924	4.0 (3.6, 4.5)	987	3.1 (2.8, 3.5)	779	2.2 (2.0, 2.4)	919	1.8 (1.7, 1.9)	793	1.5 (1.4, 1.6)	1,024	0.9 (0.9, 1.0)
3–5 y	1,639	14.9 (14.1, 15.8)	1,308	3.3 (2.9, 3.7)	1,405	2.5 (2.3, 2.7)	842	1.8 (1.6, 2.0)	960	1.5 (1.4, 1.6)	860	1.2 (1.2, 1.3)	1,297	0.8 (0.7, 0.8)
Sex														
Female	1,118	15.0 (14.1, 15.8)	1,144	3.5 (3.1, 3.9)	1,181	2.7 (2.4, 2.9)	770	1.9 (1.8, 2.1)	928	1.6 (1.5, 1.7)	781	1.3 (1.2, 1.4)	1,108	0.8 (0.7, 0.9)
Male	1,242	15.4 (14.4, 16.4)	1,088	3.6 (3.2, 4.0)	1,211	2.8 (2.5, 3.1)	851	1.9 (1.8, 2.1)	951	1.6 (1.5, 1.7)	872	1.3 (1.3, 1.4)	1,213	0.9 (0.8, 0.9)
Birthplace														
United States	2,270	15.1 (14.2, 16.1)	2,144	3.6 (3.2, 3.9)	2,276	2.7 (2.5, 3.0)	1,563	1.9 (1.8, 2.1)	1,830	1.6 (1.5, 1.7)	1,618	1.3 (1.3, 1.4)	2,252	0.8 (0.8, 0.9)
Mexico	—[b]	—[b]	55	6.3 (4.4, 8.2)	81	3.6 (2.8, 4.3)	34	3.1 (1.8, 4.4)	32	2.2 (1.8, 2.6)	10	1.8 (NA, NA)[c]	—[b]	—[b]
Other	62	16.8 (15.5, 18.1)	24	3.5 (1.8, 5.3)	34	2.8 (1.5, 4.1)	24	1.8 (1.1, 2.6)	17	1.9 (0.9, 3.0)	24	1.3 (0.7, 1.8)	69	0.8 (0.7, 1.0)
Race/ethnicity														
Non-Hispanic White	1,584	13.9 (11.5, 19.4)	658	3.1 (2.8, 3.4)	631	2.3 (2.1, 2.6)	454	1.8 (1.6, 2.0)	535	1.4 (1.4, 1.5)	536	1.3 (1.1, 1.4)	563	0.8 (0.7, 0.9)
Non-Hispanic Black	424	20.3 (19.0, 21.7)	679	5.2 (4.6, 5.8)	783	4.3 (3.6, 5.0)	439	2.8 (2.5, 3.1)	530	2.4 (2.1, 2.8)	338	1.8 (1.6, 1.9)	608	1.1 (1.0, 1.2)
Mexican American	101	15.5 (11.5, 19.4)	803	3.9 (2.9, 4.9)	827	3.1 (2.7, 3.5)	541	1.9 (1.8, 2.0)	611	1.6 (1.5, 1.7)	490	1.3 (1.2, 1.4)	526	0.8 (0.7, 0.8)
Other	—[b]	—[b]	92	4.2 (2.0, 6.3)	151	2.8 (2.2, 3.4)	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Other Hispanic	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	108	1.8 (1.3, 2.2)	99	1.8 (1.5, 2.2)	187	1.3 (1.2, 1.5)	287	0.8 (0.7, 0.9)
Other race	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	79	1.8 (1.4, 2.3)	104	1.6 (1.3, 1.9)	102	1.2 (1.0, 1.4)	337	0.8 (0.8, 0.9)
Family income-to-poverty ratio														
<1.3	828	17.7 (16.5, 19.0)	1,019	4.7 (4.0, 5.4)	1,249	3.8 (3.3, 4.2)	808	2.5 (2.2, 2.7)	936	2.0 (1.9, 2.2)	864	1.6 (1.5, 1.7)	1,149	1.0 (0.9, 1.1)
≥1.3	1,470	14.1 (13.3, 15.0)	1,004	3.1 (2.8, 3.4)	1,001	2.2 (2.0, 2.3)	686	1.6 (1.4, 1.7)	857	1.4 (1.3, 1.5)	676	1.2 (1.1, 1.3)	997	0.7 (0.7, 0.8)
Health insurance														
Yes	—[b]	—[b]	1,742	3.5 (3.1, 3.9)	1,978	2.7 (2.5, 2.9)	1,346	1.9 (1.7, 2.0)	1,640	1.6 (1.5, 1.7)	1,491	1.3 (1.2, 1.4)	2,174	0.8 (0.8, 0.9)
No	—[b]	—[b]	129	3.7 (3.0, 4.4)	409	3.1 (2.6, 3.6)	252	2.4 (2.0, 2.7)	229	1.7 (1.4, 1.9)	161	1.5 (1.3, 1.6)	144	1.0 (0.8, 1.2)
WIC														
Yes	—[b]	—[b]	540	4.7 (3.8, 5.7)	761	4.1 (3.6, 4.7)	712	2.5 (2.3, 2.7)	890	2.0 (1.8, 2.1)	952	1.5 (1.4, 1.6)	—[b]	—[b]
No	—[b]	—[b]	1,687	3.4 (3.0, 3.7)	1,627	2.4 (2.3, 2.6)	739	1.7 (1.5, 1.8)	987	1.5 (1.4, 1.5)	700	1.2 (1.1, 1.3)	—[b]	—[b]
Medicaid														
Yes	—[b]	—[b]	626	5.3 (4.2, 6.4)	984	3.9 (3.5, 4.4)	592	2.6 (2.4, 2.8)	759	2.0 (1.8, 2.1)	674	1.6 (1.5, 1.7)	1,152	0.9 (0.9, 1.0)
No	—[b]	—[b]	408	3.4 (3.1, 3.8)	1,403	2.3 (2.1, 2.5)	998	1.7 (1.6, 1.9)	1,108	1.5 (1.4, 1.6)	978	1.2 (1.2, 1.3)	1,166	0.8 (0.7, 0.8)
Housing age														
Pre-1946/Pre-1950	—[b]	—[b]	378	5.2 (4.4, 6.0)	368	3.8 (3.0, 4.6)	208	2.7 (2.4, 3.1)	242	2.1 (1.8, 2.3)	264	1.6 (1.3, 1.9)	—[b]	—[b]
1946–1972/1950–1977	—[b]	—[b]	931	3.6 (3.2, 4.0)	889	2.8 (2.6, 3.1)	341	1.8 (1.7, 2.0)	413	1.5 (1.4, 1.7)	343	1.3 (1.2, 1.5)	—[b]	—[b]
1973–present/1978–present	—[b]	—[b]	602	2.9 (2.5, 3.3)	744	2.0 (1.9, 2.2)	470	1.5 (1.3, 1.6)	528	1.3 (1.2, 1.4)	503	1.1 (1.0, 1.2)	—[b]	—[b]
Unknown	—[b]	—[b]	170	4.9 (3.7, 6.0)	351	3.6 (3.0, 4.2)	576	2.5 (2.2, 2.7)	682	2.0 (1.8, 2.2)	529	1.6 (1.5, 1.7)	—[b]	—[b]
Urbanization														
MSA ≥1 million	533	16.9 (15.7, 18.0)	1,106	3.7 (3.1, 4.2)	1,323	2.8 (2.3, 3.3)	776	1.81 (1.63, 1.99)	1,193	1.69 (1.53, 1.84)	917	1.27 (1.09, 1.45)	1,308	0.77 (0.70, 0.85)
MSA <1 million	1,827	14.7 (13.5, 15.8)	1,126	3.5 (2.9, 4.1)	1,069	2.7 (2.2, 3.1)	631	2.00 (1.68, 2.32)	438	1.46 (1.16, 1.77)	476	1.36 (0.97, 1.75)	605	0.83 (0.69, 0.96)
Non-MSA							214	2.11 (1.71, 2.51)	247	1.58 (0.76, 2.39)	260	1.45 (1.01, 1.88)	408	0.98 (0.49, 1.48)
Geographic region														
Northeast	397	15.9 (14.5, 17.3)	209	5.4 (2.4, 8.3)	268	3.3 (2.0, 4.6)	223	2.34 (1.98, 2.70)	262	2.17 (1.43, 2.91)	233	1.64 (0.97, 2.30)	311	1.08 (0.84, 1.32)
Midwest	644	15.5 (14.1, 16.8)	425	3.6 (3.2, 4.1)	405	3.3 (2.7, 3.8)	226	2.49 (1.94, 3.05)	448	1.69 (1.26, 2.12)	383	1.30 (1.23, 1.38)	503	0.94 (0.69, 1.18)
South	670	14.3 (12.0, 16.7)	821	3.4 (2.9, 3.9)	1,178	2.7 (2.3, 3.0)	716	1.95 (1.79, 2.10)	691	1.57 (1.47, 1.67)	654	1.38 (1.22, 1.53)	893	0.79 (0.72, 0.85)
West	649	15.4 (13.4, 17.3)	777	2.9 (2.3, 3.5)	541	2.1 (1.6, 2.7)	456	1.42 (1.29, 1.54)	477	1.29 (1.15, 1.43)	383	1.10 (0.92, 1.27)	614	0.70 (0.63, 0.77)

Note: BLL, blood lead level; CI, confidence interval, MSA, metropolitan statistical area; WIC, the Special Supplemental Nutrition Program for Women, Infants, and Children.
[a]Weighted estimates derived from the observed data for the study population using NHANES-specified sampling weights.
[b]Variable not assessed in this survey cycle.
[c]NA, not applicable, indicates that the upper/lower limits of a confidence interval could not be derived due to small sample sizes.

Table 3. Weighted geometric mean and 95% CI for blood lead levels in micrograms per deciliter among U.S. children ages 6–11 y,[a] overall and by selected characteristics in the National Health and Nutrition Examination Survey (NHANES), 1976–2016.

	Geometric mean (95% CI) BLLs in μg/dL[a]													
Ages 6–11 y	*n*	1976–1980	*n*	1988–1991	*n*	1991–1994	*n*	1999–2002	*n*	2003–2006	*n*	2007–2010	*n*	2011–2016
Overall	830	12.7 (11.9, 13.4)	1,584	2.4 (2.1, 2.7)	1,345	1.9 (1.8, 2.1)	1,949	1.4 (1.3, 1.4)	1,790	1.1 (1.1, 1.2)	2,020	0.9 (0.9, 1.0)	3,146	0.6 (0.6, 0.6)
Age group														
6–8 y	453	13.1 (12.2, 14.0)	756	2.5 (2.1, 3.0)	650	2.1 (1.9, 2.3)	964	1.4 (1.3, 1.6)	849	1.2 (1.1, 1.3)	986	1.0 (1.0, 1.1)	1,575	0.7 (0.6, 0.7)
9–11 y	377	12.3 (11.5, 13.0)	828	2.3 (2.1, 2.5)	695	1.8 (1.6, 2.0)	985	1.3 (1.2, 1.4)	941	1.1 (1.0, 1.1)	1,034	0.8 (0.8, 0.97)	1,571	0.6 (0.5, 0.6)
Sex														
Female	400	12.1 (11.3, 12.9)	786	2.2 (1.9, 2.5)	650	1.9 (1.7, 2.2)	954	1.3 (1.17, 1.35)	918	1.1 (1.0, 1.27)	993	0.9 (0.8, 0.9)	1,533	0.6 (0.5, 0.6)
Male	430	13.2 (12.5, 13.9)	798	2.6 (2.3, 2.9)	695	1.9 (1.7, 2.2)	995	1.4 (1.3, 1.6)	872	1.2 (1.1, 1.2)	1,027	0.9 (0.9, 1.0)	1,613	0.6 (0.6, 0.7)
Birthplace														
United States	787	12.6 (11.9, 13.4)	1,422	2.4 (2.1, 2.7)	1,264	1.9 (1.7, 2.1)	1,795	1.3 (1.2, 1.4)	1,650	1.1 (1.0, 1.2)	1,890	0.9 (0.8, 1.0)	2,963	0.6 (0.6, 0.6)
Mexico	—[b]	—[b]	115	4.9 (3.2, 6.5)	34	3.3 (2.2, 4.4)	96	2.0 (1.6, 2.4)	98	1.7 (1.5, 2.0)	62	1.1 (0.9, 1.3)	—[b]	—[b]
Other	31	14.0 (12.9, 15.1)	39	2.3 (1.5, 3.1)	46	2.4 (1.5, 3.3)	58	1.7 (0.8, 2.6)	42	1.37 (0.9, 1.7)	66	1.0 (0.8, 1.2)	183	0.8 (0.7, 0.8)
Race/ethnicity														
Non-Hispanic White	617	12.0 (11.2, 12.7)	460	2.1 (1.8, 2.4)	310	1.7 (1.5, 1.9)	499	1.2 (1.1, 1.4)	456	1.0 (0.9, 1.17)	600	0.8 (0.8, 0.9)	789	0.6 (0.5, 0.6)
Non-Hispanic Black	122	16.2 (14.9, 17.5)	389	3.9 (3.3, 4.5)	585	3.0 (2.6, 3.3)	626	2.0 (1.8, 2.2)	575	1.6 (1.4, 1.8)	446	1.2 (1.1, 1.4)	817	0.8 (0.7, 0.8)
Mexican American	27	13.5 (7.9, 19.0)	678	2.9 (2.2, 3.6)	379	2.2 (1.9, 2.5)	664	1.4 (1.3, 1.5)	596	1.2 (1.1, 1.4)	599	0.9 (0.8, 1.0)	724	0.8 (0.5, 0.6)
Other	—[b]	—[b]	57	2.5 (1.3, 3.7)	71	2.0 (1.4, 2.6)	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Other Hispanic	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	88	1.3 (0.8, 1.7)	55	1.2 (0.8, 1.5)	260	0.9 (0.8, 1.1)	370	0.6 (0.5, 0.6)
Other race	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	72	1.3 (1.0, 1.6)	108	1.1 (0.9, 1.3)	115	0.9 (0.8, 1.0)	446	0.7 (0.6, 0.7)
Family income-to-poverty ratio														
<1.3	259	13.8 (12.6, 14.9)	697	3.6 (3.1, 4.1)	679	2.7 (2.4, 3.0)	822	1.8 (1.7, 1.9)	748	1.6 (1.3, 1.6)	883	1.1 (1.0, 1.2)	1,407	0.7 (0.7, 0.7)
≥1.3	549	12.2 (11.5, 12.9)	746	2.0 (1.8, 2.2)	584	1.6 (1.4, 1.8)	964	1.1 (1.0, 1.2)	980	1.0 (0.9, 1.1)	1,001	0.8 (0.8, 0.9)	1,539	0.6 (0.5, 0.6)
Health insurance														
Yes	—[b]	—[b]	1,186	2.3 (2.0, 2.6)	1,068	1.9 (1.7, 2.0)	1,595	1.3 (1.2, 1.4)	1,507	1.1 (1.0, 1.2)	1,787	0.9 (0.9, 1.0)	2,915	0.6 (0.6, 0.6)
No	—[b]	—[b]	180	3.0 (2.3, 3.8)	276	2.5 (2.1, 2.8)	328	1.6 (1.4, 1.95)	273	1.2 (1.1, 1.4)	229	1.0 (0.9, 1.1)	229	0.67 (0.59, 0.75)
WIC														
Yes	—[b]	—[b]	167	3.7 (2.7, 4.8)	218	2.6 (1.9, 3.3)	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
No	—[b]	—[b]	1,413	2.3 (2.1, 2.6)	1,127	1.9 (1.7, 2.0)	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Medicaid														
Yes	—[b]	—[b]	331	3.8 (3.0, 4.7)	399	3.4 (2.9, 3.8)	501	1.8 (1.7, 1.9)	525	1.5 (1.3, 1.7)	647	1.1 (1.0, 1.2)	1,350	0.7 (0.6, 0.7)
No	—[b]	—[b]	579	2.3 (2.1, 2.5)	943	1.7 (1.6, 1.9)	1,415	1.3 (1.2, 1.3)	1,254	1.0 (1.0, 1.1)	1,369	0.9 (0.8, 0.9)	1,794	0.6 (0.6, 0.6)
Housing age														
Pre-1946/Pre-1950	—[b]	—[b]	263	3.4 (2.7, 4.1)	224	2.6 (2.3, 3.0)	238	1.4 (1.3, 1.6)	203	1.4 (1.2, 1.6)	294	1.1 (1.0, 1.2)	—[b]	—[b]
1946–1972/1950–1977	—[b]	—[b]	681	2.5 (2.1, 2.8)	494	1.9 (1.7, 2.2)	405	1.2 (1.1, 1.4)	460	1.1 (1.0, 1.2)	432	0.9 (0.8, 0.9)	—[b]	—[b]
1973–present/1978–present	—[b]	—[b]	460	1.9 (1.6, 2.2)	403	1.4 (1.3, 1.6)	643	1.2 (1.0, 1.3)	572	0.9 (0.9, 1.0)	747	0.9 (0.7, 0.9)	—[b]	—[b]
Unknown	—[b]	—[b]	98	4.3 (3.3, 5.4)	180	3.2 (2.5, 3.8)	636	1.9 (1.7, 2.1)	536	1.7 (1.5, 1.8)	528	1.1 (1.0, 1.2)	—[b]	—[b]
Urbanization														
MSA ≥1 million	199	14.0 (12.4, 15.7)	753	2.4 (1.9, 2.9)	674	2.0 (1.7, 2.3)	983	1.33 (1.17, 1.49)	1,173	1.18 (1.09, 1.28)	1,179	0.90 (0.81, 1.00)	1,868	0.57 (0.53, 0.60)
MSA <1 million	631	12.2 (11.2, 13.1)	831	2.4 (2.1, 2.8)	671	1.9 (1.6, 2.2)	746	1.37 (1.22, 1.53)	406	1.04 (0.78, 1.29)	588	0.93 (0.79, 1.07)	731	0.61 (0.54, 0.69)
Non-MSA							220	1.35 (0.99, 1.71)	211	1.09 (0.13, 2.05)	253	0.90 (0.65, 1.15)	547	0.70 (0.47, 0.92)
Geographic region														
Northeast	175	13.5 (12.2, 14.9)	132	3.7 (1.9, 5.4)	159	2.2 (1.6, 2.8)	255	1.54 (1.24, 1.84)	273	1.54 (0.95, 2.12)	320	1.08 (0.86, 1.31)	417	0.74 (0.62, 0.86)
Midwest	222	12.1 (11.1, 13.1)	295	2.6 (1.8, 3.5)	234	2.1 (1.6, 2.7)	298	1.54 (1.19, 1.90)	387	1.12 (0.87, 1.38)	427	0.88 (0.80, 0.95)	586	0.64 (0.52, 0.77)
South	238	11.9 (9.9, 14.0)	504	2.2 (1.9, 2.5)	751	1.9 (1.7, 2.2)	794	1.37 (1.20, 1.53)	667	1.09 (0.97, 1.22)	753	0.93 (0.82, 1.05)	1,311	0.60 (0.54, 0.65)
West	195	13.4 (11.7, 15.2)	653	2.0 (1.3, 2.6)	201	1.6 (0.7, 2.5)	602	1.12 (1.05, 1.19)	463	0.94 (0.80, 1.09)	520	0.78 (0.72, 0.84)	832	0.53 (0.51, 0.55)

Note: BLL, blood lead level; CI, confidence interval; MSA, metropolitan statistical area; WIC, the Special Supplemental Nutrition Program for Women, Infants, and Children.
[a]Weighted estimates derived from the observed data for the study population using NHANES-specified sampling weights.
[b]Variable not assessed in this survey cycle.

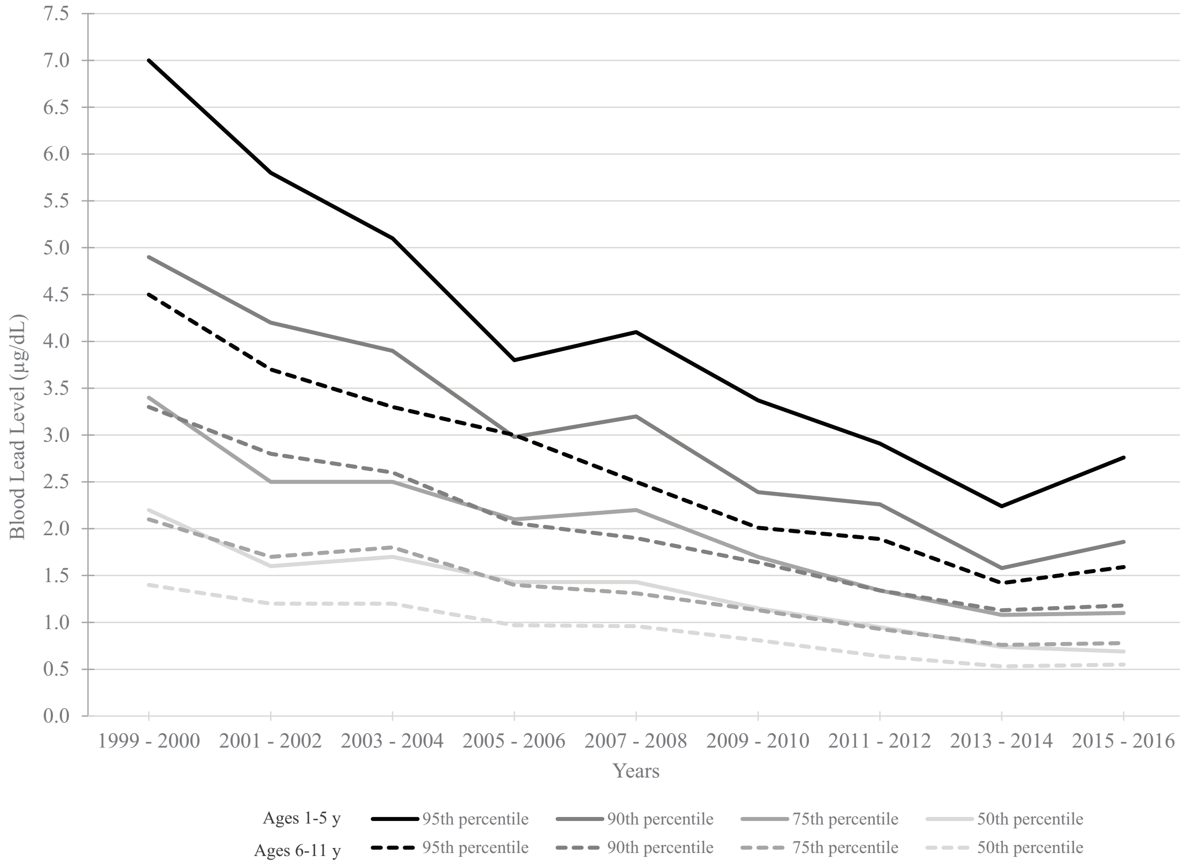

Figure 2. Selected percentiles of blood lead concentrations (in µg/dL) for U.S. children ages 1–5 y (solid line) and ages 6–11 y (dashed line) in the National Health and Nutrition Examination Survey (NHANES), 1999–2016, by 2-y survey cycle (years); data are shown in Table S2.

being born in the United States), receiving Medicaid, and a FIPR <1.3 were associated with higher estimated prevalence of BLL ≥5 µg/dL in children ages 1–5 y and 6–11 y (Tables 4 and 5). For example, in 1999–2002, the estimated prevalence of BLL ≥5 µg/dL among children ages 1–5 years of age, respectively, was 18.4% (95% CI: 14.3, 23.4) among non-Hispanic Black children in comparison with 7.3% (95% CI: 4.2, 12.3) among non-Hispanic White children (Table 4). In 2011–2016, this estimate decreased to 2.4% (95% CI: 1.3, 4.4) among non-Hispanic Black children and 1.5% (95% CI: 0.6, 3.9) among non-Hispanic White children (Table 5). Among children 6–11 years of age, observations were similar. Estimated prevalence of BLL ≥5 µg/dL were highest among children living in pre-1946 housing or those with "unknown" housing age.

Almost all children in NHANES II, regardless of FIPR, had a BLL ≥5 µg/dL. Children with FIPR <1.3 had higher estimated prevalence of BLL ≥5 µg/dL. In the period 2011–2016, the estimated prevalence of BLL ≥5 µg/dL for children ages 1–5 y with a FIPR <1.3 was 1.7% (95% CI: 0.8, 3.6) vs. 0.7% (95% CI: 0.2, 2.0) among children with a FIPR ≥1.3. This is a decrease from the period 1999–2002, where the estimated prevalence was 13.1% (95% CI: 9.9, 17.2) for children with a FIPR <1.3 vs. 4.4% (95% CI: 2.8, 7.0) of children with a FIPR ≥1.3. In 1991–1994, children ages 1–5 y with FIPR <1.3 had a 35.6% (95% CI: 27.2, 45.0) estimated prevalence of BLL ≥5 µg/dL in comparison with those with FIPR ≥1.3 (9.8% (95% CI: 6.7, 14.2)). For children ages 6–11 y, the 2011–2016 estimated prevalence among children with a FIPR <1.3 was 0.4% (95% CI: 0.1, 1.1) vs. 0.1% (95% CI: 0.0, 0.5) for FIPR ≥1.3, a decrease from the 1999–2002 estimated prevalence of 6.1% (95% CI: 4.1, 9.0) vs. 1.1% (95% CI: 0.5, 2.6) among children with a FIPR ≥1.3. In comparison, from 1991–1994 the estimated prevalence among those with FIPR <1.3 was 16.8% (95% CI: 12.7, 21.9), and from 1976–1980 it was almost 100%.

Age of housing was not collected from 2011 to 2016; therefore, no estimates are available for these years. In most recent estimates from 2007 to 2010, estimated prevalence of BLL ≥5 µg/dL for children ages 1–5 y living in pre-1950 housing was 5.4% (95% CI: 1.8, 15.0) vs. 0.4% (95% CI: 0.1, 1.2) living in newer housing built from 1978 to present. This is a decline from 1991–1994 and 1988–1991, where the estimated prevalence of BLL ≥5 µg/dL for children ages 1–5 y living in pre-1946 housing was 37.3% (95% CI: 27.4, 48.5) and 49.3% (95% CI: 39.0, 59.6), respectively. For children ages 6–11 y, the estimated prevalence of BLL ≥5 µg/dL was 1.2% (95% CI: 0.4, 3.0) vs. 0.1% (95% CI: 0.0, 1.0) in 2007–2010, which is also a decrease from 1991–1994 [18.7% (95% CI: 13.9, 24.7)] and 1988–1991 [28.6% (95% CI: 19.2, 40.3)]. In general, higher GM BLL were observed in the Northeast and Midwest regions and in MSAs with greater than 1 million population, although these differences were not consistent and became less apparent over time.

Discussion

Overall, BLLs in U.S. children ages 1–11 y have decreased substantially over the past 40 y. NHANES measurements of BLLs have played a key role in monitoring the decline in population lead exposure among U.S. children and adults and influenced key public health actions and national policy around lead poisoning prevention. In 2012, CDC defined a blood lead reference value based on the 97.5th percentile of NHANES blood lead distribution in children ages 1–5 y equal to 5 µg/dL as the most highly

Table 4. Weighted estimated prevalence and 95% CI of BLLs ≥5 μg/dL among U.S. children ages 1–5 y[a] overall and by selected characteristics in the National Health and Nutrition Examination Survey (NHANES), 1976–2016.

	Estimated prevalence (95% CI) of BLLs ≥5 μg/dL[a]													
Ages 1–5 y	*n*	1976–1980	*n*	1988–1991	*n*	1991–1994	*n*	1999–2002	*n*	2003–2006	*n*	2007–2010	*n*	2011–2016
Overall	2,360	99.8 (99.4, 99.9)	2,232	31.4 (26.0, 37.3)	2,392	21.0 (16.0, 27.0)	1,621	8.7 (6.5, 11.5)	1,879	4.1 (2.9, 5.8)	1,653	2.6 (1.7, 4.2)	2,321	1.3 (0.7, 2.4)[d]
Age group														
1–2 y	721	99.5 (98.1, 99.9)	924	39.0 (31.4, 47.2)	987	26.7 (20.7, 33.6)	779	12.2 (9.3, 15.8)	919	5.7 (4.4, 7.3)	793	3.1 (2.2, 4.5)	1,024	2.1 (1.0, 4.6)[d]
3–5 y	1,639	99.9 (99.6, 100.0)	1,308	26.7 (21.5, 32.8)	1,405	17.3 (12.4, 23.6)	842	6.4 (4.1, 10.0)	960	3.1 (1.7, 5.5)	860	2.3 (1.1, 4.9)[d]	1,297	0.7 (0.3, 1.7)[d]
Sex														
Female	1,118	99.7 (98.7, 99.9)	1,144	31.3 (26.7, 36.3)	1,181	18.9 (14.2, 24.7)	770	8.2 (6.2, 10.7)	928	4.3 (3.1, 6.1)	781	2.8 (1.7, 4.4)	1,108	0.9 (0.5, 1.8)[d]
Male	1,242	99.9 (99.9, 100.0)	1,088	31.5 (24.9, 38.9)	1,211	22.9 (17.0, 30.1)	851	9.1 (6.1, 13.3)	951	3.9 (2.6, 6.0)	872	2.5 (1.5, 4.3)	1,213	1.6 (0.8, 3.2)[d]
Birthplace														
United States	2,270	99.8 (99.4, 99.9)	2,144	31.3 (26.0, 37.1)	2,276	20.8 (16.0, 26.5)	1,563	8.6 (6.4, 11.5)	1,830	3.9 (2.7, 5.6)	1,618	2.6 (1.6, 4.2)	2,252	1.3 (0.7, 2.4)[d]
Mexico	—[b]	—[b]	55	58.8 (33.8, 79.9)	81	28.4 (16.0, 45.4)	34	30.8 (17.5, 48.4)	32	17.9 (8.1, 34.9)[d]	10	0.0 (NA, NA)[c]	—[b]	—[b]
Other	62	100.0 (NA, NA)[c]	24	25.4 (8.7, 54.9)[d]	34	25.1 (8.5, 54.6)[d]	24	0.0 (NA, NA)[c]	17	11.5 (3.3, 33.5)[d]	24	4.0 (0.9, 16.3)[d]	69	1.1 (0.1, 7.3)[d]
Race/ethnicity														
Non-Hispanic White	1,584	99.8 (99.2, 99.9)	658	24.6 (20.1, 29.6)	631	13.5 (9.1, 19.6)	454	7.3 (4.2, 12.3)	535	2.3 (1.5, 3.4)	536	2.4 (0.9, 6.0)[d]	563	1.5 (0.6, 3.9)[d]
Non-Hispanic Black	424	100.0 (NA, NA)[c]	679	53.1 (46.1, 60.1)	783	41.9 (31.7, 52.8)	439	18.4 (14.3, 23.4)	530	12.3 (7.1, 20.6)	338	5.6 (3.5, 8.7)	608	2.4 (1.3, 4.4)[d]
Mexican American	101	99.4 (96.7, 99.9)	803	34.9 (23.4, 48.5)	827	22.8 (17.2, 29.7)	541	7.4 (4.9, 10.9)	611	2.6 (1.3, 5.0)[d]	490	1.9 (0.9, 4.2)[d]	526	0.3 (0.1, 1.3)[d]
Other	—[b]	—[b]	92	37.1 (16.7, 63.5)[d]	151	25.0 (14.3, 40.0)	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Other Hispanic	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	108	5.2 (1.9, 13.6)[d]	99	5.4 (2.0, 13.3)[d]	187	1.4 (0.5, 3.9)[d]	287	0.6 (0.2, 2.3)[d]
Other race	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	79	5.1 (1.5, 16.1)[d]	104	4.8 (1.4, 15.6)[d]	102	1.5 (0.5, 4.8)[d]	337	0.9 (0.3, 2.8)[d]
Family income-to-poverty ratio														
<1.3	828	99.7 (99.0, 99.9)	1,019	45.6 (37.0, 54.4)	1,249	35.6 (27.2, 45.0)	808	13.1 (9.9, 17.2)	936	8.2 (5.5, 12.0)	864	4.5 (3.1, 6.4)	1,149	1.7 (0.8, 3.6)[d]
≥1.3	1,470	99.8 (99.0, 100.0)	1,004	23.5 (19.0, 28.6)	1,001	9.8 (6.7, 14.2)	686	4.4 (2.8, 7.0)	857	1.6 (0.9, 3.1)[d]	676	1.2 (0.3, 5.1)[d]	997	0.7 (0.2, 2.0)[d]
Health insurance														
Yes	—[b]	—[b]	1,742	29.9 (24.1, 36.4)	1,978	20.1 (15.3, 26.0)	1,346	13.1 (9.9, 17.2)	1,640	8.2 (5.5, 12.0)	1,491	4.5 (3.1, 6.4)	2,174	1.7 (0.8, 3.6)[d]
No	—[b]	—[b]	129	31.7 (21.6, 43.7)	409	28.0 (18.4, 40.3)	252	4.4 (2.8, 7.0)	229	1.6 (0.9, 3.1)[d]	161	1.2 (0.3, 5.1)[d]	144	0.7 (0.2, 2.0)[d]
WIC														
Yes	—[b]	—[b]	540	44.0 (33.5, 55.0)	761	38.4 (29.3, 48.4)	712	13.5 (9.5, 18.9)	890	7.1 (4.9, 10.4)	952	3.5 (2.5, 5.0)	—[b]	—[b]
No	—[b]	—[b]	1,687	28.8 (24.1, 33.9)	1,627	16.0 (12.4, 20.5)	739	6.0 (4.2, 8.5)	987	2.6 (1.7, 4.2)	700	2.0 (0.8, 5.0)[d]	—[b]	—[b]
Medicaid														
Yes	—[b]	—[b]	626	51.0 (39.9, 61.9)	984	38.5 (30.0, 47.7)	592	13.5 (9.5, 18.9)	759	7.1 (4.9, 10.4)	674	3.5 (2.5, 5.0)	1,152	—[b]
No	—[b]	—[b]	408	28.4 (22.7, 35.0)	1,403	13.0 (9.9, 16.9)	998	6.0 (4.2, 8.5)	1,108	2.6 (1.7, 4.2)	978	2.0 (0.8, 5.0)[d]	1,166	—[b]
Housing age														
Pre-1946/Pre-1950	—[b]	—[b]	378	49.3 (39.0, 59.6)	368	37.3 (27.4, 48.5)	208	18.4 (13.4, 24.7)	242	8.8 (5.6, 13.7)	264	5.4 (1.8, 15.0)[d]	—[b]	—[b]
1946–1972/1950–1977	—[b]	—[b]	931	34.0 (28.4, 40.2)	889	21.0 (14.7, 29.1)	341	5.3 (3.1, 8.9)	413	2.2 (1.0, 4.8)[d]	343	1.3 (0.7, 2.6)[d]	—[b]	—[b]
1973–present/1978–present	—[b]	—[b]	602	19.5 (14.3, 26.0)	744	9.2 (6.3, 13.2)	470	2.1 (1.1, 4.1)[d]	528	1.4 (0.7, 2.6)[d]	503	0.4 (0.1, 1.2)[d]	—[b]	—[b]
Unknown	—[b]	—[b]	170	46.2 (31.9, 61.2)	351	30.7 (22.8, 40.0)	576	14.6 (10.9, 19.2)	682	7.5 (4.1, 13.2)	529	5.2 (3.5, 7.7)	—[b]	—[b]
Urbanization														
MSA ≥1 million	533	100.0 (NA, NA)[c]	1,106	33.7 (27.7, 40.3)	1,323	22.4 (14.2, 33.5)	776	5.4 (3.1, 9.4)	1,193	4.8 (2.8, 8.1)	917	1.9 (1.0, 3.3)	1,308	1.0 (0.5, 2.3)[d]
MSA <1 million Non-MSA	1,827	99.7 (99.2, 99.9)	1,126	29.7 (21.8, 39.1)	1,069	19.3 (13.0, 27.7)	631 214	12.0 (8.5, 16.7) 7.4 (4.5, 11.9)	438 247	4.5 (1.8, 10.4)[d] 1.2 (0.4, 3.8)[d]	476 260	4.2 (1.5, 10.8)[d] 2.4 (1.2, 4.7)[d]	605 408	1.6 (0.5, 5.2)[d] —[e]
Geographic region														
Northeast	397	99.6 (99.4, 99.7)	209	54.4 (36.7, 71.0)	268	33.4 (19.9, 50.4)	223	15.8 (11.0, 22.2)	262	9.2 (5.1, 16.1)	233	6.1 (1.7, 19.4)[d]	311	3.6 (1.4, 9.1)[d]
Midwest	644	99.9 (98.9, 100.0)	425	31.0 (25.5, 37.1)	405	31.5 (22.8, 41.6)	226	17.1 (12.1, 23.5)	448	7.3 (3.3, 15.5)[d]	383	3.7 (3.0, 4.5)	503	2.9 (1.1, 7.0)[d]
South	670	99.6 (97.5, 99.9)	821	28.6 (23.9, 33.8)	1,178	17.1 (12.1, 23.6)	716	5.9 (4.2, 8.3)	691	1.5 (0.9, 2.4)	654	1.1 (0.5, 2.4)[d]	893	—[e]
West	649	99.9 (99.4, 100.0)	777	20.2 (12.7, 30.7)	541	9.0 (4.6, 17.0)[d]	456	2.6 (1.6, 4.2)	477	1.1 (0.5, 2.6)[d]	383	1.7 (0.7, 3.7)[d]	614	—[e]

Note: BLL, blood lead level; CI, confidence interval; MSA, metropolitan statistical area; WIC, the Special Supplemental Nutrition Program for Women, Infants, and Children.
[a]Weighted estimates derived from the observed data for the study population using NHANES-specified sampling weights.
[b]Variable not assessed in this survey cycle.
[c]NA, not applicable, indicates that the upper/lower limits of a confidence interval could not be derived due to small sample sizes.
[d]Relative Standard Error (RSE) greater than or equal to 30% indicates estimate is statistically unreliable.
[e]Data suppressed due to small cell size for counts and corresponding estimates.

Table 5. Weighted estimated prevalence and 95% CI of BLLs ≥5 μg/dL among U.S. children ages 6–11 y,[a] overall and by selected characteristics in the National Health and Nutrition Examination Survey (NHANES), 1976–2016.

	Estimated prevalence (95% CI) of BLLs ≥5 μg/dL[a]													
Ages 6–11 y	*n*	1976–1980	*n*	1988–1991	*n*	1991–1994	*n*	1999–2002	*n*	2003–2006	*n*	2007–2010	*n*	2011–2016
Overall	830	99.7 (98.6, 99.9)	1,584	15.0 (11.3, 19.7)	1,345	9.5 (7.3, 12.2)	1,949	3.0 (1.9, 4.6)	1,790	1.3 (0.7, 2.6)[d]	2,020	0.4 (0.2, 0.8)	3,146	0.5 (0.1, 0.5)[d]
Age group														
6–8 y	453	99.6 (96.8, 100.0)	756	18.2 (12.9, 25.1)	650	11.7 (8.9, 15.3)	964	4.0 (2.2, 7.1)	849	2.2 (1.1, 4.4)[d]	986	0.7 (0.4, 1.3)[d]	1,575	0.3 (0.1, 0.9)[d]
9–11 y	377	99.8 (98.1, 100.0)	828	12.0 (9.0, 15.8)	695	7.5 (5.3, 10.4)	985	2.0 (1.3, 2.9)	941	0.5 (0.2, 1.5)[d]	1,034	0.2 (0.0, 1.0)[d]	1,571	0.1 (0.0, 0.4)[d]
Sex														
Female	400	99.7 (98.0, 100.0)	786	11.8 (7.5, 18.0)	650	11.3 (7.2, 17.3)	954	2.6 (1.7, 4.1)	918	1.2 (0.7, 2.3)[d]	993	0.5 (0.2, 1.2)[d]	1,533	0.2 (0.1, 0.6)[d]
Male	430	99.6 (97.0, 100.0)	798	18.0 (13.7, 23.2)	695	7.7 (5.2, 11.3)	995	3.3 (1.9, 5.5)	872	1.4 (0.7, 3.1)[d]	1,027	0.4 (0.1, 0.9)[d]	1,613	0.2 (0.1, 0.7)[d]
Birthplace														
United States	787	99.7 (98.5, 99.9)	1,422	14.6 (11.0, 19.2)	1,264	9.0 (6.7, 12.0)	1,795	2.7 (1.4, 5.0)[d]	1,650	1.3 (0.6, 2.7)[d]	1,890	0.4 (0.2, 0.8)[d]	2,963	0.2 (0.1, 0.5)[d]
Mexico	—[b]	—[b]	115	54.7 (39.1, 69.4)	34	20.2 (11.6, 32.8)	96	5.8 (2.5, 12.8)[d]	98	3.2 (1.3, 7.7)[d]	62	0.0 (NA, NA)[c]	—[b]	—[b]
Other	31	100.0 (NA, NA)[c]	39	10.7 (3.7, 27.2)[d]	46	15.4 (4.2, 42.9)[d]	58	8.5 (2.1, 28.7)[d]	42	0.7 (0.1, 5.1)[d]	66	0.7 (0.1, 5.3)[d]	183	0.0 (NA, NA)[c]
Race/ethnicity														
Non-Hispanic White	617	99.6 (98.1, 99.9)	460	9.8 (6.6, 14.4)	310	5.3 (3.2, 8.7)	499	2.1 (1.1, 4.0)[d]	456	0.8 (0.3, 2.1)[d]	600	0.3 (0.1, 0.9)[d]	789	0.2 (0.0, 0.7)[d]
Non-Hispanic Black	122	100.0 (NA, NA)[c]	389	33.5 (24.9, 43.5)	585	23.2 (17.8, 29.6)	626	7.6 (3.9, 14.4)[d]	575	5.6 (1.9, 10.6)[d]	446	1.7 (0.8, 3.9)[d]	817	0.4 (0.1, 1.8)[d]
Mexican American	27	100.0 (NA, NA)[c]	678	24.8 (15.8, 36.7)	379	11.6 (7.3, 18.0)	664	1.9 (1.0, 3.5)	596	1.0 (0.4, 2.6)[d]	599	0.0 (NA, NA)[c]	724	0.3 (0.1, 0.9)[d]
Other	—[b]	—[b]	57	14.8 (4.8, 37.6)[d]	71	12.4 (5.7, 24.9)[d]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Other Hispanic	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	88	1.3 (0.3, 5.8)[d]	55	0.0 (NA, NA)[c]	260	0.4 (0.1, 2.2)[d]	370	0.5 (0.1, 2.1)[d]
Other race	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	72	4.4 (0.5, 31.3)[d]	108	0.0 (NA, NA)[c]	115	0.0 (NA, NA)[c]	446	0.0 (NA, NA)[c]
Family income-to-poverty ratio														
<1.3	259	99.5 (96.6, 99.9)	697	31.1 (24.0, 39.2)	679	16.8 (12.7, 21.9)	822	6.1 (4.1, 9.0)	748	3.0 (1.4, 6.3)[d]	883	1.1 (0.5, 2.2)[d]	1,407	0.4 (0.1, 1.1)[d]
≥1.3	549	99.7 (97.8, 100.0)	746	7.8 (4.9, 12.0)	584	4.8 (2.3, 9.8)[d]	964	1.1 (0.5, 2.6)[d]	980	0.5 (0.2, 1.1)[d]	1,001	0.1 (0.0, 0.4)[d]	1,539	0.1 (0.0, 0.5)[d]
Health insurance														
Yes	—[b]	—[b]	1,186	12.9 (8.6, 19.0)	1,068	9.2 (6.9, 12.2)	1,595	2.6 (1.6, 4.2)	1,507	1.3 (0.6, 2.7)[d]	1,787	0.4 (0.2, 0.8)[d]	2,915	0.2 (0.1, 0.5)[d]
No	—[b]	—[b]	180	26.8 (18.4, 37.2)	276	11.1 (7.3, 16.5)	328	5.0 (1.9, 12.4)	273	0.7 (0.3, 2.0)[d]	229	0.9 (0.2, 4.3)[d]	229	0.3 (0.1, 2.4)[d]
WIC														
Yes	—[b]	—[b]	167	33.0 (20.9, 48.0)	218	18.6 (11.4, 28.8)	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
No	—[b]	—[b]	1,413	13.9 (10.4, 18.3)	1,127	8.4 (6.3, 11.0)	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Medicaid														
Yes	—[b]	—[b]	331	33.8 (24.2, 44.9)	399	27.4 (20.9, 35.1)	501	4.7 (2.7, 8.1)	525	3.0 (1.0, 8.2)[d]	647	0.4 (0.1, 1.8)[d]	1,350	0.3 (0.1, 0.9)[d]
No	—[b]	—[b]	579	13.3 (9.8, 17.8)	943	5.9 (3.7, 9.2)	1,415	2.5 (1.3, 4.8)[d]	1,254	0.7 (0.3, 1.9)[d]	1,369	0.4 (0.2, 0.8)[d]	1,794	0.2 (0.1, 0.6)[d]
Housing age														
Pre-1946/Pre-1950	—[b]	—[b]	263	28.6 (19.2, 40.3)	224	18.7 (13.9, 24.7)	238	3.5 (1.4, 8.3)[d]	203	2.6 (0.9, 7.3)[d]	294	1.2 (0.4, 3.0)[d]	—[b]	—[b]
1946–1972/1950–1977	—[b]	—[b]	681	15.6 (11.3, 21.1)	494	7.6 (5.0, 11.4)	405	2.2 (0.8, 6.2)[d]	460	0.4 (0.1, 2.1)[d]	432	0.0 (NA, NA)[d]	—[b]	—[b]
1973–present/1978–present	—[b]	—[b]	460	5.6 (3.5, 8.8)	403	3.3 (1.2, 8.5)[d]	643	0.6 (0.2, 1.8)[d]	572	0.1 (0.02, 0.5)[d]	747	0.1 (0.0, 1.0)[d]	—[b]	—[b]
Unknown	—[b]	—[b]	98	45.5 (30.0, 61.9)	180	23.1 (11.2, 30.8)	636	7.8 (5.0, 11.9)	536	4.8 (2.0, 11.0)[d]	528	1.1 (0.4, 2.6)[d]	—[b]	—[b]
Urbanization														
MSA ≥1 million	199	100.0 (NA, NA)[c]	753	16.1 (10.7, 23.5)	674	9.8 (5.6, 16.6)	983	1.9 (0.8, 4.5)[d]	1,173	1.5 (0.8, 2.9)[d]	1,179	0.5 (0.2, 1.2)[d]	1,868	—[e]
MSA <1 million	631	100.0 (NA, NA)[c]	831	14.0 (9.0, 21.1)	671	9.2 (5.9, 14.0)	746	4.3 (2.2, 8.5)[d]	406	1.7 (0.4, 7.4)[d]	588	—[e]	731	—[e]
Non-MSA							220	1.4 (0.3, 7.1)[d]	211	—[e]	253	—[e]	547	0.8 (0.4, 1.3)[d]
Geographic region														
Northeast	175	100.0 (NA, NA)[c]	132	35.2 (20.4, 53.5)	159	12.4 (9.8, 15.5)	255	4.1 (1.6, 10.2)[d]	273	3.8 (0.9, 14.1)[d]	320	1.2 (0.5, 3.2)[d]	417	—[e]
Midwest	222	100.0 (NA, NA)[c]	295	16.9 (9.4, 28.5)	234	15.8 (10.0, 24.1)	298	7.5 (3.9, 14.1)[d]	387	2.2 (0.6, 7.7)[d]	427	0.5 (0.1, 1.9)[d]	586	—[e]
South	238	98.8 (94.7, 99.7)	504	11.2 (8.0, 15.5)	751	6.1 (3.5, 10.2)	794	1.5 (0.7, 3.0)[d]	667	—[e]	753	—[e]	1,311	0.3 (0.1, 0.7)[d]
West	195	100.0 (NA, NA)[c]	653	7.5 (3.8, 14.3)[d]	201	4.5 (1.5, 12.6)[d]	602	1.1 (0.3, 5.0)[d]	463	—[e]	520	—[e]	832	—[e]

Note: BLL, blood lead level; CI, confidence interval; MSA, metropolitan statistical area.
[a]Weighted estimates derived from the observed data for the study population using NHANES-specified sampling weights.
[b]Variable not assessed in this survey cycle.
[c]NA, not applicable, indicates that the upper/lower limits of a confidence interval could not be derived due to small sample sizes.
[d]Relative Standard Error (RSE) greater than or equal to 30% indicates estimate is statistically unreliable.
[e]Data suppressed due to small cell size for counts and corresponding estimates.

exposed group (ACCLPP 2012). NHANES is designed to produce nationally representative, generalizable results for the U.S. population, and our analyses indicate that significant progress has been made in reducing the number of children with elevated BLLs. Despite these notable declines in population exposures to lead over time, an estimated 385,775 children ages 1–11 y had BLLs greater than or equal to the CDC blood lead reference value of 5 μg/dL (NHANES 2011–2016).

Although virtually all children had BLLs ≥5 μg/dL in 1976–1980, the estimated prevalence in 2011–2016 of BLLs ≥5 μg/dL was less than 2% of children ages 1–5 y and less than 1% of those ages 6–11 y. Despite this enormous public health achievement, a portion of children, particularly those of minority and low-income backgrounds, still have a higher estimated prevalence of BLL ≥5 μg/dL (Health Impact Project 2017). Our results indicate that sociodemographic characteristics associated with lead exposure risk in younger children (ages 1–5 y), such as income level and older housing, are also risk factors for older children (ages 6–11 y) and that these risk factors have persisted over time.

Previous publications have revealed similar trends in NHANES BLL data and identified disparities in BLLs by race/ethnicity and SES (Aoki and Brody 2018; Mahaffey et al. 1982; Pirkle et al. 1994). Non-Hispanic Black children and those from low-income households have persistently been found to have higher BLLs than non-Hispanic White children and those from higher income households. NHANES data for 2011–2016 suggest that these groups continue to be particularly vulnerable to lead exposure as evidenced by higher prevalence of BLLs ≥5 μg/dL. When considering BLL differences for specific sociodemographic groups, however, environmental risk factors, including age and condition of housing, should be kept in mind. Also, nationally representative surveys such as NHANES may not capture children in certain high-risk groups, such as refugee children <16 years of age residing in the United States, who have been shown to have a higher prevalence of elevated lead levels (Pezzi et al. 2019).

NHANES is a nationally representative sample of the U.S. noninstitutionalized population at all ages but was not designed to produce BLL prevalence estimates at the regional, state or local level (Johnson et al. 2013). Blood lead surveillance data from state and local childhood lead poisoning prevention programs can be used to complement national NHANES estimates by identifying local risk factors for elevated BLLs and aiding local prevention efforts (Angelon-Gaetz et al. 2018; Bressler et al. 2019). Despite combining multiple cycles of survey data, the population subsample of children with valid blood lead test results is limited. We did not have the ability to conduct detailed subgroup or multivariate analyses, especially for the most recent data, due to small cell sizes particularly at higher BLLs. Estimates with RSE >30% are considered statistically unstable and, therefore, should be reviewed with caution.

More than 20% of all children ages 1–11 y sampled in NHANES were missing BLLs during the 40-y analysis period. Missing BLL data among participants could potentially bias estimates if these children had different exposure risks compared with those who were tested. For example, there is the potential for bias due to differential response rates by age (1–5 y and 6–11 y) in the survey periods because age is related to lead exposure (i.e., younger children may have higher BLL due to behavior patterns (e.g., pica), and/or older children may have higher cumulative body burden that is released from bone during period of growth). However, we did not assess these associations in our analysis. Decreasing laboratory analytic LOD for BLLs over the 40 y of NHANES blood lead analyses could have contributed to a higher GM for earlier years relative to more recent cycles, though most results were far above the LOD in the early cycles. NHANES BLL measurements have played a key role in monitoring the decline in U.S. population exposures influencing both national policy and public health action.

Our analysis provides important information on long-term trends in BLLs among U.S. children ages 1–11 y over a 40-y period. Of note, certain characteristics are consistently associated with higher blood lead levels over time, including non-Hispanic Black race/ethnicity, poverty, and older housing age. Although blood lead levels have generally declined in children over the past 40 y in the United States, lead exposure remains an important public health problem among children particularly for those in high-risk groups.

Although NHANES helps to identify certain risk factors associated with lead exposure (e.g., older housing), it cannot determine the specific source(s) of lead exposure for surveyed children. Given the detrimental health effects and long-term impacts of lead exposure in children, creating lead-safe environments for all children is critical. Deteriorated lead-based paint and dust in older housing remain the primary sources of lead exposure for U.S. children. In the U.S., approximately 23 million housing units have one or more lead-based paint hazards (HUD 2011). This number includes 3.6 million households with children <6 of age. In addition, an estimated 6.1 million lead service lines are still in place across the nation (Dignam et al. 2019). Other sources of lead exposure that exist today include consumer products, imported foods, and workplace take-home exposures (Ettinger et al. 2019). Continued, coordinated public health effort at national, state, and local levels can build on past achievements and provide lead-safe environments for all children.

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References

ACCLPP (Advisory Committee on Childhood Lead Poisoning Prevention). 2012. Low Level Lead Exposure Harms Children: A Renewed Call for Primary Prevention. Report of the advisory committee on childhood lead poisoning prevention of the centers for disease control and prevention. Atlanta, GA: Centers for Disease Control and Prevention.

Alarcon WA, State Adult Blood Lead Epidemiology and Surveillance (ABLES) Program Investigators. 2016. Elevated blood lead levels among employed adults - United States, 1994–2013. MMWR Morb Mortal Wkly Rep 63(55):59–65, PMID: 27736830, https://doi.org/10.15585/mmwr.mm6355a5.

Angelon-Gaetz KA, Klaus C, Chaudhry EA, Bean DK. 2018. Lead in spices, herbal remedies, and ceremonial powders sampled from home investigations for children with elevated blood lead levels - North Carolina, 2011–2018. MMWR Morb Mortal Wkly Rep 67(46):1290–1294, PMID: 30462630, https://doi.org/10.15585/mmwr.mm6746a2.

Aoki Y, Brody DJ. 2018. WIC participation and blood lead levels among children 1-5 years: 2007–2014. Environ Health Perspect 126(6):067011, PMID: 29961657, https://doi.org/10.1289/EHP2384.

Bellinger DC, Needleman HL. 2003. Intellectual impairment and blood lead levels. N Engl J Med 349(5):500–502, PMID: 12890850, https://doi.org/10.1056/NEJM200307313490515.

Bressler JM, Yoder S, Cooper S, McLaughlin J. 2019. Blood lead surveillance and exposure sources among Alaska children. J Public Health Manag Pract 25(1):S71–S75, PMID: 30507773, https://doi.org/10.1097/PHH.0000000000000877.

Brody DJ, Pirkle JL, Kramer RA, Flegal KM, Matte TD, Gunter EW, et al. 1994. Blood lead levels in the US population. Phase 1 of the Third National Health and

Nutrition Examination Survey (NHANES III, 1988 to 1991). JAMA 272(4):277–283, PMID: 8028140, https://doi.org/10.1001/jama.272.4.277.

Caldwell KL, Cheng P-Y, Jarrett JM, Makhmudov A, Vance K, Ward CD, et al. 2017. Measurement challenges at low blood lead levels. Pediatrics 140(2):e20170272, PMID: 28771411, https://doi.org/10.1542/peds.2017-0272.

CBPP (Center on Budget and Policy Priorities). 2019. *A Quick Guide to SNAP Eligibility and Benefits*. Washington, DC: Center on Budget and Policy Priorities.

CDC (Centers for Disease Control and Prevention). 1985. *Laboratory procedures used by the Clinical Chemistry Division, Centers For Disease Control, for the Second Health and Nutrition Examination Survey (HANES II) 1976–1980*. Atlanta, GA: Centers for Disease Control.

CDC. 2009. *National Health and Nutrition Examination Survey (NHANES) Laboratory Procedures Manual, July 2009*. Atlanta, GA: Centers for Disease Control.

CDC. 2018. *National Health and Nutrition Examination Survey Analytic Guidelines, 2011–2014 and 2015–2016*. Atlanta, GA: Centers for Disease Control.

CDC. 2019. National Health and Nutrition Examination Survey. https://www.cdc.gov/nchs/nhanes/about_nhanes.htm [accessed 8 November 2018].

Census Bureau. 2019. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019 (NST-EST2019-01). https://www.census.gov/data/datasets/time-series/demo/popest/2010s-national-total.html [accessed 29 December 2020].

Dignam T, Kaufmann RB, LeStourgeon L, Brown MJ. 2019. Control of lead sources in the United States, 1970–2017: public health progress and current challenges to eliminating lead exposure. J Public Health Manag Pract 25(1):S13–S22, PMID: 30507765, https://doi.org/10.1097/PHH.0000000000000889.

Ettinger AS, Egan KB, Homa DM, Brown MJ. 2020. Blood lead levels in U.S. women of childbearing age, 1976–2016. Environ Health Perspect 128(1):17012, PMID: 31944143, https://doi.org/10.1289/EHP5925.

Ettinger AS, Ruckart PZ, Dignam T. 2019. Lead poisoning prevention: the unfinished agenda. J Public Health Manag Pract 25(1):S1–S2, PMID: 30507762, https://doi.org/10.1097/PHH.0000000000000902.

Gunter EW, Lewis BG, Koncikowski SM. 1996. Laboratory Procedures Used for the Third National Health and Nutrition Examination Survey (NHANES III), 1988–1994. Atlanta, GA: National Center for Environmental Health.

Hanna-Attisha M, LaChance J, Sadler RC, Champney Schnepp A. 2016. Elevated blood lead levels in children associated with the flint drinking water crisis: a spatial analysis of risk and public health response. Am J Public Health 106(2):283–290, PMID: 26691115, https://doi.org/10.2105/AJPH.2015.303003.

HUD (U.S. Department of Housing and Urban Development). 2011. American Healthy Homes Survey (AHHS). Lead and arsenic findings. Washington, DC: U.S. Department of Housing and Urban Development Office of Healthy Homes and Lead Hazard Control.

Johnson CL, Paulose-Ram R, Ogden CL, Carroll MD, Kruszon-Moran D, Dohrmann SM, et al. 2013. *National Health and Nutrition Examination Survey: Analytic Guidelines: 1999–2010*. Vital Health Stat 2 (161):1–24, PMID: 25090154.

Jones RL, Homa DM, Meyer PA, Brody DJ, Caldwell KL, Pirkle JL, et al. 2009. Trends in blood lead levels and blood lead testing among US children aged 1 to 5 years, 1988–2004. Pediatrics 123(3):e376–e385, PMID: 19254973, https://doi.org/10.1542/peds.2007-3608.

Lanphear BP, Hornung R, Khoury J, Yolton K, Baghurst P, Bellinger DC, et al. 2005. Low-level environmental lead exposure and children's intellectual function: an international pooled analysis. Environ Health Perspect 113(7):894–899, PMID: 16002379, https://doi.org/10.1289/ehp.7688.

Mahaffey KR, Annest JL, Roberts J, Murphy RS. 1982. National estimates of blood lead levels: United States, 1976–1980—association with selected demographic and socioeconomic factors. N Engl J Med 307(10):573–579, PMID: 7110203, https://doi.org/10.1056/NEJM198209023071001.

McDowell A, Engel A, Massey JT, Maurer K. 1981. Plan and operation of the Second National Health and Nutrition Examination Survey 1976-80. Vital Health Stat 1 15:1–144, PMID: 7344293.

McLaine P, Navas-Acien A, Lee R, Simon P, Diener-West M, Agnew J. 2013. Elevated blood lead levels and reading readiness at the start of kindergarten. Pediatrics 131(6):1081–1089, PMID: 23669514, https://doi.org/10.1542/peds.2012-2277.

Min MO, Singer LT, Kirchner HL, Minnes S, Short E, Hussain Z, et al. 2009. Cognitive development and low-level lead exposure in poly-drug exposed children. Neurotoxicol Teratol 31(4):225–231, PMID: 19345261, https://doi.org/10.1016/j.ntt.2009.03.002.

Miranda ML, Kim D, Reiter J, Overstreet Galeano MA, Maxson P. 2009. Environmental contributors to the achievement gap. Neurotoxicology 30(6):1019–1024, PMID: 19643133, https://doi.org/10.1016/j.neuro.2009.07.012.

NCHS (National Center for Health Statistics). 1996. *Analytic and Reporting Guidelines: The Third National Health and Nutrition Examination Survey, NHANES III (1988-94)*. Hyattsville, MD: Centers for Disease Control and Prevention.

NCHS. 2017. NCHS Urban-Rural Classification Scheme for Counties. https://www.cdc.gov/nchs/data_access/urban_rural.htm [accessed 1 July 2020].

NTP (National Toxicology Program). 2012. *NTP Monograph on Health Effects of Low-Level Lead*. Durham, NC: U.S. Department of Health and Human Services.

Paschal DC, Caldwell KL, Ting BG. 1995. Determination of lead in whole blood using inductively coupled argon plasma mass spectrometry with isotope dilution. J Anal Atom Spectrom 10(5):367–370, https://doi.org/10.1039/ja9951000367.

Pezzi C, Lee D, Kennedy L, Aguirre J, Titus M, Ford R, et al. 2019. Blood lead levels among resettled refugee children in select US states, 2010–2014. Pediatrics 143(5):e20182591, PMID: 30996119, https://doi.org/10.1542/peds.2018-2591.

Pfadenhauer LM, Burns J, Rohwer A, Rehfuess EA. 2016. Effectiveness of interventions to reduce exposure to lead through consumer products and drinking water: a systematic review. Environ Res 147:525–536, PMID: 26990846, https://doi.org/10.1016/j.envres.2016.03.004.

Pirkle JL, Brody DJ, Gunter EW, Kramer RA, Paschal DC, Flegal KM, et al. 1994. The decline in blood lead levels in the United States. The National Health and Nutrition Examination Surveys (NHANES). JAMA 272(4):284–291, PMID: 8028141.

Pirkle JL, Kaufmann RB, Brody DJ, Hickman T, Gunter EW, Paschal DC. 1998. Exposure of the U.S. population to lead, 1991–1994. Environ Health Perspect 106(11):745–750, PMID: 9799191, https://doi.org/10.1289/ehp.98106745.

President's Task Force on Environmental Health Risks and Safety Risks to Children. 2018. The Federal Action Plan to Reduce Childhood Lead Exposures and Associated Health Impacts. https://ptfceh.niehs.nih.gov/resources/lead_action_plan_508.pdf.

Raymond J, Wheeler W, Brown MJ, Centers for Disease Control and Prevention. 2014. Lead screening and prevalence of blood lead levels in children aged 1-2 years–child blood lead surveillance system, United States, 2002–2010 and National Health and Nutrition Examination Survey, United States, 1999–2010. MMWR Suppl 63(2):36–42, PMID: 25208256.

Renner R. 2009. Out of plumb: when water treatment causes lead contamination. Environ Health Perspect 117(12):A542–A547, PMID: 20049189, https://doi.org/10.1289/ehp.117-a542.

Reuben A, Caspi A, Belsky DW, Broadbent J, Harrington H, Sugden K, et al. 2017. Association of childhood blood lead levels with cognitive function and socioeconomic status at age 38 years and with IQ change and socioeconomic mobility between childhood and adulthood. JAMA 317(12):1244–1251, PMID: 28350927, https://doi.org/10.1001/jama.2017.1712.

Health Impact Project. 2017. 10 Policies to Prevent and Respond to Childhood Lead Exposure: An Assessment of the Risks Communities Face and Key Federal, State and Local Solutions. Washington, DC: Robert Wood Johnson Foundation, The PEW Charitable Trust. https://www.pewtrusts.org/-/media/assets/2017/08/hip_childhood_lead_poisoning_report.pdf [accessed 29 December 2020].

Ruckart PZ, Ettinger AS, Hanna-Attisha M, Jones N, Davis SI, Breysse PN. 2019. The Flint water crisis: a coordinated public health emergency response and recovery initiative. J Public Health Manag Pract 25(suppl 1):S84–S90, PMID: 30507775, https://doi.org/10.1097/PHH.0000000000000871.

Triantafyllidou S, Le T, Gallagher D, Edwards M. 2014. Reduced risk estimations after remediation of lead (pb) in drinking water at two US school districts. Sci Total Environ 466–467:1011–1021, PMID: 23988746, https://doi.org/10.1016/j.scitotenv.2013.07.111.

Tsoi MF, Cheung CL, Cheung TT, Cheung BM. 2016. Continual decrease in blood lead level in Americans: United States National Health Nutrition and Examination Survey 1999–2014. Am J Med 129(11):1213–1218, PMID: 27341956, https://doi.org/10.1016/j.amjmed.2016.05.042.

Wheeler W, Brown MJ. 2013. Blood lead levels in children aged 1-5 years – United States, 1999–2010. MMWR Morb Mortal Wkly Rep 62(13):245–248, PMID: 23552225.